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Yu.G. Maystrenko et al

CORPS OF ENGINEERS, U.S. ARMY
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It is established experimentally that higher water vegetation after dying off and mineralization can serve as one of the main sources of accumulating organic and biogenic substances in a water medium. The quantity of saprophytic microorganisms and rate of accumulation organic and biogenic substances are the highest in the first ten-day periods of vegetation contact with water. To the second month the amount of biochemically constant organic substances and the ratio C:N increase, the ratio of ammonium nitrogen to organic one and

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cont the quantity of saprophytic, proteolytic, anaerobic, cellulose and ammonificating bacteria decrease. During this period the nitrification intensity grows. At maximum output of organic and biogenic substances the content of organic nitrogen and carbon is 1.3--10 times and that of mineral derivative of nitrogen and phosphorus is 11--70 times as high as the background one.

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ROLE OF HIGHER AQUATIC VEGETATION IN THE ACCUMULATION OF ORGANIC AND BIOGENIC SUBSTANCES IN INLAND WATERS

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[Article by Yu. G. Maystrenko, A. I. Denisova, V. M. Bagnyuk and Zh. M. Aryamova, Institute of Hydrobiology, Ukrainian SSR Academy of Sciences, Kiev]

[Text] It was found that after dying and mineralization, higher aquatic plants can serve as sources for organic and biogenic substances accumulating in bodies of water. Data presented assist in clarifying the role of higher aquatic plants in forming the hydrochemical regime of existing inland waters and can be used in predicting the regime of biogenic and organic substances in newly formed bodies of water.

Accumulation and dynamics of organic and biogenic substances in retarded-flow inland waters (reservoirs, lakes, ponds and drowned river valleys) are significantly caused by higher aquatic vegetation growing in the bodies of water. Higher aquatic plants contain 7.1-23 percent proteins, 2-17 percent crude proteins, 1.1-3.0 percent fats and 16.7-42.0 percent cellular tissue [7]. Under favorable hydrothermal conditions, after dying and microbiological degradation of enormous masses of vegetation, large amounts of diverse organic substances and biogenic elements are liberated; these stimulate the growth--in the bodies of water--of animal and plant organisms influencing water quality and interfering with water utilization for economic and household purposes.

Currently, executing the general plan of hydrotechnical construction in the USSR very acutely poses the problem of the quality of natural waters used in the national economy. So clarifying all factors bearing on the quality of water in natural and artificial bodies of water is the paramount task in the designing of reservoirs and in predicting their water quality. Also, while predicting salt composition poses no special difficulties, for organic matter and biogenic elements this is very difficult owing to the very sparse information on factors causing their accumulation, dynamics and transformation.

Recent literature has very limited information on the kinetics and decomposition rates and certain species of aquatic plants in water caused by the intense development and vital activity of saprophytic microorganisms [1-3,6,9, 13]. Available data, granted all their value, do not enable us to form an idea of the quantitative aspect of the process and to calculate the content of constituents of organic and biogenic substances entering the body of water during the degradation and mineralization of higher aquatic plants, a most vital necessity when predicting the levels of these constituents in inland waters.

This report gives the results of an experimental study of the incursion rate of organic and biogenic substances into a body of water during the degradation and mineralization of groups of higher aquatic plants populating a reservoir in the Dneprovskiy cascade. The work was done in the hydrochemistry division of the Institute of Hydrobiology, Ukrainian SSR Academy of Sciences; it is part of integrated studies clarifying the role of vegetation in forming the hydrochemical regime of reservoirs.

Method. Experiments with higher aquatic plants--willow grass [Polygonum amphibium L.], perfoliate pondweed [Potamogeton perfoliatus L.], hornwort [Ceratophyllum demersum L.], cat-tail, water thyme [Elodea] and common water plaintain [Alisma plantago-aquatica L.]--were performed in presterilized 30-liter glass bottles. To protect against air contamination, the bottles were covered with sterile cotton wool pads and periodically shaken. Before each experiments, plants collected in the shallow part of the Kiev Reservoir were ground in the natural state and covered with reservoir water in a 1:100 ratio. The constant water level in the experiments after sampling was maintained for the analysis by adding fresh water on the basis of the natural water turnover in reservoirs (three to five times a year). The exposure time was 300 days. The experiment was conducted in the temperature range of 17-23°.

Hydrochemical and microbiological investigations were made to elucidate the mechanism of bacterial degradation and accumulation in water of organic and biogenic substances. In the first case, the organic carbon, nitrogen, phosphorus, permanganate and bichromate oxidizability, humic compounds, phenols, pH and oxygen were determined, along with CO_2, all forms of mineral nitrogen and phosphorus, suspended and solute iron, silicon, hydrogen sulfide and carbonates. In the second case, saprophytic bacteria, proteolytic, ammonifying, nitrifying, denitrifying and also aerobic and anaerobic cellulosic microorganisms were determined. Water samples were taken in sterile conditions. The hydrochemical and microbiological analysis was done by the standard methods [4,8,10-12].

Results of Study

Gas regime. In the first 3 days' exposure, the oxygen content in the water of the test vessels dropped by 2-46 times compared to the background; by the fifth to the fifteenth day it fell to analytical zero. This decrease was particularly marked (by 16-46 times) in vessels containing willow grass, hornwort and water thyme, and less so (2-13 times)--in vessels containing common

water plaintain and perfoliate pondweed. As Figure 1 shows, anaerobic conditions of mineralization of vegetation in the experiments with willow grass persisted for 75-120 days; in experiments with perfoliate pondweed, hornwort, water thyme and common water plaintain--for 45-55 days; thereafter, with decrease in the concentration of easily oxidized organic compounds the oxygen content rose and by the end of exposure (270 days) reached fairly high values (52-76 percent of saturation); the exception was the experiments with willow grass and perfoliate pondweed (23-30 percent). An increase in the oxygen content in the water of the vessels began from the end of the second month of exposure. In spite of the acute oxygen shortage during this period, saprophytic bacteria in the vessel water were quite numerous (20,500-424,500 colonies per ml); this points to intense degradation of the substrate even in anaerobic conditions.

The CO_2 concentration during the first three days in the experiments with willow grass, common water plaintain and water thyme rose by 38-50 times compared with the background, while in the remaining days, by 1.1-25 times; the CO_2 concentration reached a maximum by the 10-25th day of exposure, then fell to its initial values (except for the vessels housing willow grass, hornwort and common water plaintain, where the CO_2 content was 1.3-2.4 times higher than the background value).

The pH varied only slightly: in the 10-90 days span it fell by 1.1-1.5 times compared with the background; by the end of the experiments it reached its initial value. Its observed drop was due significantly to carboxylic acids accumulating in the water during microbial decomposition of organic compounds in higher aquatic plants and also owing to deamination of amino acids in anaerobic conditions.

The dynamics of oxygen and carbon dioxide gas, as we see (see Figure 1), depends on the dynamics of organic matter entering water as the organic matter in vegetation mineralizes: corresponding to the minimum oxygen content in water is the maximum content of organic carbon and carbon dioxide gas and, vice versa.

Regime of Organic and Biogenic Substances

Significant amounts of organic and biogenic matter accumulated even in the first few days of exposure in the vessel water. The content of organic substances reached maximum values mainly by the 15th day of exposure; here the organic carbon concentrations were increased compared to the background by 1.3-4.0 times, the organic nitrogen content--by 4-10 times, the organic phosphorus content--by 33-146 times, humic compounds--by 1.6-2.2 times and phenols --by 1.6-2.2 times (Table 1, Figure 2). The maximum color index, 1.2-2.4 times higher than the background, was noted by the 46th day.

Organic matter accumulated most intensively in the first five-day period and thereafter diminished somewhat. The dynamics of organic carbon and organic nitrogen showed some disparity in how the maxima alternated; evidently this derived from the nonuniform assimilation of these constituents by the microorganisms. The organic matter started decreasing in content mainly from the

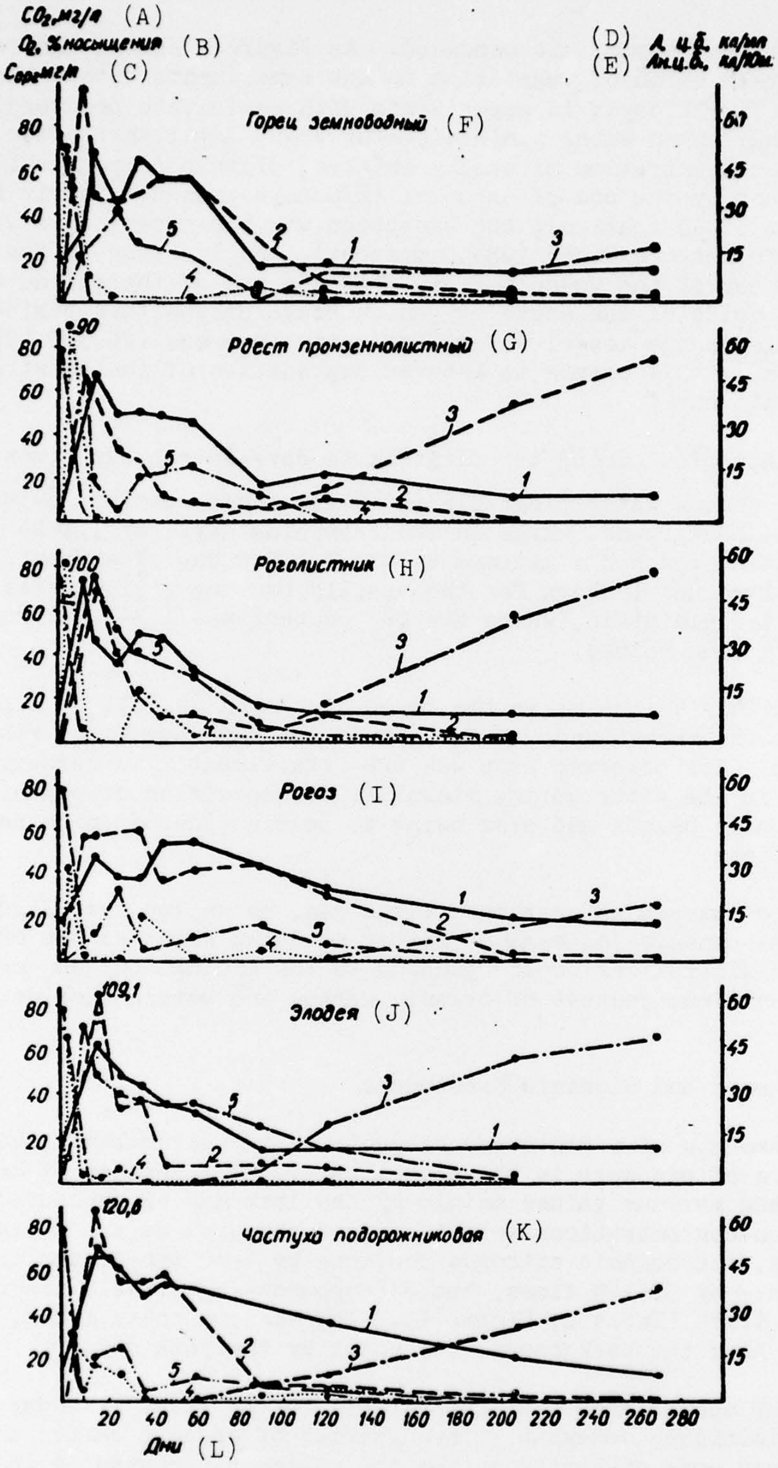


Figure 1. [Caption on following page]

[Caption to Figure 1 on preceding page]

Figure 1. Dynamics of gases, organic matter, aerobic and anaerobic cellulosic bacteria in experiments with higher aquatic vegetation:

1. organic carbon 2. CO_2
3. O_2 4. aerobic cellulosic bacteria (A. ч. б.)
5. anaerobic cellulosic bacteria (Ан. ч. б.)

Key:

A. CO_2, mg/liter
B. O_2, percent of saturation
C. $C_{organic}$, mg/liter
D. Aerobic cellulosic bacteria, colonies per ml
E. Anaerobic cellulosic bacteria, colonies per ml
F. Willow grass
G. Perfoliate pondweed
H. Hornwort
I. Cat-tail
J. Water thyme
K. Common water plaintain
L. Days

second ten-day period and continued to the end of the exposure (270 days). During this period their concentrations in the experiment exceeded the control values: carbon--by 1.1-2 times; nitrogen--by 6-20 times; phosphorus--by 0-6 times; humic compounds--by 0-1.5 times; the color index rose by 1.1-1.5 times; and the phenol content stayed practically the same as the control.

The accumulation of biogenic elements from leaching out of vegetation and by mineralizing of organic matter entering the water in the first 15 days reached maximum values mostly by the close of the second month of exposure. Here the content of ammonia nitrogen went up by 11-37 times compared to the background, phosphate phosphorus--by 14-70 times and silicon--by 1.8-3.7 times. Preceding the maximum accumulation of biogenic elements in this period was the maximum count of microorganisms mineralizing organic compounds (bacteria grown on beef-extract agar [BAE], proteolytic and ammonifying). For example, the count of ammonifying bacteria microorganisms at the start of month two of incubation reached 4.5 million colonies/ml. The decline in the content of biogenic substances in the water started generally from the sixth ten-day period and by the end of exposure reached their concentration value in the background: ammonia nitrogen--by 1.2-2 times; nitrate nitrogen--by 0-1.1 times; phosphorus of insoluble phosphates--by 10-28 times, phosphorus of soluble phosphates--by 19-45 times and silicon--by 0-2 times.

A similar correlation is characteristic also of bacterial processes of degradation, tapering off by the end of the incubation of vegetation. The count of microorganisms causing organic matter to decompose by this time approached the control value. The sole exception was the nitrifying bacteria; its count rose with the increase in the oxygen concentration. Thus, by the 15-35th day there were no nitrifiers in some variants and by the 60-130th day their content fluctuated from 6 to 90 colonies/10 ml water. The increase in the count of nitrifying bacteria as higher aquatic plants decomposed testifies to improved sanitary conditions and water quality. As shown by the reduced hydrochemical and microbiological indicators, the incursion of organic and biogenic substances during the mineralizing of plant matter can last the whole year; however, most of the matter accumulates in the water the first 2 months.

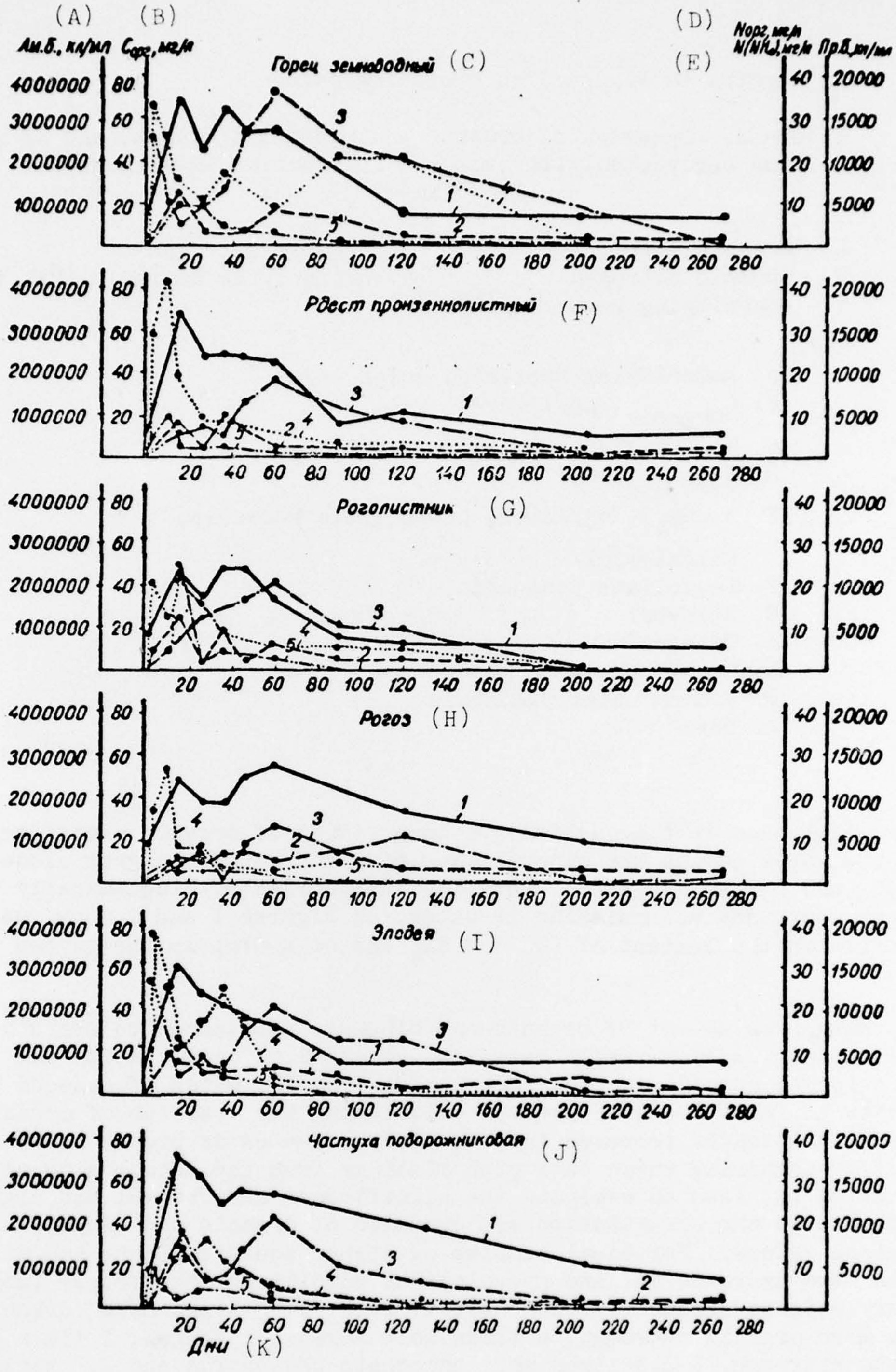
Favorable hydrothermal conditions even in the first few weeks favor the accumulation in water of unstable organic substances with a narrow ratio of organic carbon to organic nitrogen. This process is attended by vigorous growth of saprophytic and proteolytic bacteria. The maximum development they showed in vessels storing willow grass, perfoliate pondweed, cat-tail and water thyme outpaced, usually by 12-20 days, the maximum organic nitrogen content in the water, and in vessels storing hornwort and common water plaintain--coincided with this maximum. In vessels with higher counts of proteolytic bacteria (willow grass, perfoliate pondweed, water thyme and common water plaintain) organic matter accumulated at a C:N ratio from 4 to 5, while in vessels with lower bacterial counts (cat-tail and hornwort)--a C:N ratio to 7.

By ammonification and nonuniform absorption by bacteria of carbon and nitrogen from the water at reduced C:N ratios during the first 2 months, the vessels showed the accumulation of ammonia nitrogen, whose concentration later, with development of the nitrifying bacteria at higher C:N values, decreased. Participating in the accumulation of ammonia ions in the water were also the denitrifying bacteria; their count in this degradation phase reached 110,000-140,000 colonies/ml water.

The content of ammonia nitrogen began dropping from the time oxygen appeared in the water and nitrifying bacteria began developing. The concentrations of nitrogen NO_2' and NO_3' began climbing at the same time.

Preceding the rise in the content of organic carbon in the water and the rise in the permanganate and bichromate oxidizabilities was always a vigorous development of saprophytic and cellulosic microorganisms. Here the first maximum in carbon accumulation was preceded by a maximum in the development of aerobic (to 100 colonies/ml), while the second maximum in carbon accumulation was preceded by a maximum in the development of anaerobic cellulosic bacteria (19-40 colonies/10 ml water).

While cleavage of complex organic (protein) compounds by proteolytic bacteria occurred during the first month of exposure, ammonifying reached its maximum by the 26-36th day and stayed at a relatively high level to the 60th day; this is shown also by the drop in the ratio of organic carbon to ammonia nitrogen (from 19-22 in the background to 1.5-6.0 in the experiments), with maximum concentrations of NH_4^+ nitrogen and an increase in the ratio of NH_4^+ nitrogen to organic nitrogen (from 0.7-0.8 in the control to 2.6-7.6 in the experiments).



[Caption to Figure 2 on the following page]

[Caption to Figure 2 on preceding page]

Figure 2. Dynamics of organic and mineral nitrogen, and of ammonifying and proteolytic bacteria in experiments with higher aquatic plants:

1. organic carbon
2. organic nitrogen
3. ammonia nitrogen
4. proteolytic bacteria (Пр. б.)
5. ammonifying bacteria (Ам. б.)

Key:

A. Ammonifying bacteria, colonies/ml
B. $C_{organic}$, mg/liter
C. Willow grass
D. $N_{organic}$, mg/liter
E. N (NH_4), mg/liter, proteolytic bacteria, colonies/ml
F. Perfoliate pondweed
G. Hornwort
H. Cat-tail
I. Water thyme
J. Common water plaintain
K. Days

Observed changes in the qualitative composition of organic matter released into the water during the mineralizing of plant material agree closely with the CO_2 and oxygen dynamics. The rise in the rate of biochemically unstable organic compounds accumulating in water, as Figures 1 and 2 show, was attended by a rise in the content of CO_2 and $NH_4^{\cdot}$ and by a drop in the oxygen concentration.

Even though the amount of organic and biogenic substances released into the water depends on diametrally opposite processes of accumulation and consumption owing to degradation and the release from the water of gaseous products, the data in Table 2 can be used in calculating the fraction of organic and biogenic substances released into the body of water as higher aquatic plants die off. Comparing these data with findings from the decomposing of arboreal vegetation [8] lets us evaluate the significance of arboreal and higher aquatic vegetation in the accumulation and dynamics of organic and biogenic substances in inland waters. For equal samples of higher aquatic plants and mixed trees, in the same hydrothermal and hydrological conditions, the former (converted to air-dry weight) produce in each unit of water 1.43 times more carbon, 2.23 times more organic nitrogen, 6 times more ammonia nitrogen, 2 times more nitrate nitrogen, 2-3.5 times more phosphate phosphorus and 2.2 times more silicon--than the latter do. The indicators listed (see Table 2) give us an idea of the order of magnitude of the amounts of organic and biogenic substances released by higher aquatic plants as individual plant groups die off

Table 1. Content of Biogenic and Organic Substances in Vessels Containing Higher Aquatic Vegetation

(1) Ингредиенты	(2) Фон	(3) Дни											
		3-й (4)	5-й (5)	10-й (6)	15-й (7)	25-й (8)	40-й (9)	45-й (10)	60-й (11)	90-й (12)	170-й (13)	205-й (14)	270-й (15)
Горец земноводный (16)													
$PO_{4\,общ}'''$, мг P/л (17)	0,112	1,57	1,80	1,94	2,14	3,88	3,30	5,30	3,36	4,32	3,82	3,35	3,12
$PO_{4\,раств}'''$, мг P/л (18)	0,068	1,22	1,59	1,94	2,04	3,68	3,05	3,56	4,100	4,78	4,32	2,088	2,144
NO_3', мг N/л (19)	0,495	0,460	0,408	0,470	0,460	0,340	0,170	0,125	0,230	0,240	0,148	0,308	0,565
Si, мг/л (20)	5,0	7,29	9,0	8,0	6,44	6,88	5,69	3,39	6,19	9,72	10,6	11,07	10,0
Цветность, градусы (21)	133	94	100	100	145	145	133	177	—	160	145	133	77
Перманганатная окисляемость, мг O/л (22)	19,5	60,0	57,6	52,7	64,3	39,4	52,0	50,4	43,2	28,32	28,24	18,64	13,56
Бихроматная окисляемость, мг O/л (23)	34,6	195,8	195,8	—	179,6	117,6	166,44	144,0	150,0	—	42,24	35,55	36,0
Фенолы, мг/л (24)	0,012	—	0,025	—	0,075	—	—	0,075	—	0,032	0,015	0,007	0,015
Рдест пронзеннолистный (25)													
$PO_{4\,общ}'''$, мг P/л (17)	0,112	1,26	1,36	1,31	1,408	2,48	1,44	2,24	1,72	2,54	1,80	1,050	1,50
$PO_{4\,раств}'''$, мг P/л (18)	0,068	1,10	1,10	1,24	0,935	1,65	1,40	1,83	2,31	2,70	2,04	1,345	1,248
NO_3', мг N/л (19)	0,495	0,480	0,520	0,520	0,700	0,420	0,450	0,155	0,362	0,520	0,800	0,805	0,500
Si, мг/л (20)	5,0	6,78	10,0	7,05	6,66	5,0	5,69	7,22	5,50	11,7	11,3	8,30	10,0
Цветность, градусы (21)	133	100	114	114	200	206	160	177	—	145	160	123	71
Перманганатная окисляемость, мг O/л (22)	19,5	57,6	52,8	56,8	56,6	54,2	57,6	47,2	40,0	27,52	28,24	15,04	11,29
Бихроматная окисляемость, мг O/л (23)	34,6	156,9	114,2	176,0	177,6	126,8	133,1	72,0	120,0	42,24	56,32	27,68	32,4
Фенолы, мг/л (24)	0,012	—	0,012	—	0,062	—	—	0,015	—	следы (30)	0,011	0,006	0,013

[Table 1, Continued]

Роголистник (26)													
PO_4''' общ, мг P/л (17)	0,112	0,420	0,960	1,968	1,672	3,240	2,24	2,70	2,48	3,06	2,04	1,248	1,42
PO_4''' раств, мг P/л (18)	0,068	0,290	0,450	1,415	0,935	3,12	2,05	2,35	2,68	2,92	2,24	1,155	1,308
NO_3', мг N/л (19)	0,495	0,360	0,382	0,900	0,570	0,420	0,450	0,220	0,372	0,400	0,500	0,590	0,600
Si, мг/л (20)	5,0	2,01	4,10	5,0	4,0	4,54	5,90	7,22	5,50	11,66	14,2	18,52	11,30
Цветность, градусы (21)	133	114	114	106	177	228	133	200	—	145	160	100	63
Перманганатная окисляемость, мг O/л (22)	19,5	22,1	33,6	43,2	43,0	33,3	36,0	32,8	32,8	23,28	23,84	13,45	10,33
Бихроматная окисляемость, мг O/л (23)	34,6	65,3	65,3	193,6	96,9	63,4	133,1	128,0	90,0	42,24	35,20	31,16	32,4
Фенолы, мг/л (24)	0,012	—	0,012	—	0,022	—	—	0,009	—	0,009	0,014	0,005	0,085
Рогоз (27)													
PO_4''' общ, мг P/л (17)	0,112	0,396	0,700	1,704	2,05	3,74	2,54	3,22	2,54	3,06	3,22	1,705	1,54
PO_4''' раств, мг P/л (18)	0,068	0,242	0,525	1,305	1,595	3,19	2,61	3,01	2,75	3,00	3,14	1,91	1,65
NO_3', мг N/л (19)	0,495	0,210	0,180	0,256	0,764	0,26	0,50	0,22	0,252	0,340	0,265	0,212	0,168
Si, мг/л (20)	5,0	2,20	3,80	5,46	4,56	4,54	5,79	6,50	7,22	7,98	8,90	9,02	4,06
Цветность, градусы (21)	133	106	106	84	145	145	133	160	—	178	177	178	91
Перманганатная окисляемость, мг O/л (22)	19,5	21,8	28,0	31,0	38,0	36,4	47,2	58,4	52,8	40,9	41,4	26,9	20,03
Бихроматная окисляемость, мг O/л (23)	34,6	81,6	49,0	—	72,7	79,2	99,8	67,0	150,4	—	91,5	51,35	43,2
Фенолы, мг/л (24)	0,012	—	0,015	—	0,017	—	—	0,03	—	—	0,016	0,007	0,014

[Table 1, Concluded]

(1) Ингредиенты	(2) Фон	(3) Дни											
		3-й (4)	5-й (5)	10-й (6)	15-й (7)	25-й (8)	40-й (9)	45-й (10)	60-й (11)	90-й (12)	120-й (13)	205-й (14)	270-й (15)
Элодея (28)													
PO_4''' общ, мг P/л (17)	0,112	1,60	2,24	4,48	4,02	4,92	6,30	4,62	4,18	4,48	3,22	1,824	1,680
PO_4''' раств, мг P/л (18)	0,068	1,50	1,92	2,68	3,44	4,42	3,93	4,14	4,14	4,56	3,06	1,850	1,340
NO_3', мг N/л (19)	0,495	0,415	0,430	0,40	0,235	0,60	0,49	0,34	0,44	0,51	0,17	0,256	0,40
Si, мг/л (20)	5,0	3,80	5,0	7,05	5,0	5,55	3,95	6,50	5,50	8,75	7,39	9,02	5,13
Цветность, градусы (21)	133	114	114	123	200	320	100	228	—	160	177	123	67
Перманганатная окисляемость, мг O/л (22)	19,5	39,2	36,0	48,0	54,2	49,6	44,8	39,2	32,8	27,5	23,84	16,62	10,33
Бихроматная окисляемость, мг O/л (23)	34,6	16,32	130,6	—	202,0	126,7	116,5	96,0	90,0	42,24	42,24	35,5	43,2
Фенолы, мг/л (24)	0,012	—	0,016	—	0,157	—	—	0,008	—	следы (30)	0,006	0,007	0,017
Частуха подорожниковая (29)													
PO_4''' общ, мг P/л (17)	0,112	0,672	1,80	2,78	1,64	4,60	3,30	3,30	2,92	3,66	2,54	2,61	2,35
PO_4''' раств, мг P/л (18)	0,068	0,471	1,10	2,50	1,27	4,21	2,16	2,54	3,12	3,66	3,36	2,41	1,972
NO_3', мг N/л (19)	0,495	0,370	0,470	0,284	0,576	0,26	0,160	0,22	0,150	0,350	0,190	0,115	0,300
Si, мг/л (20)	5,0	4,30	8,0	13,32	6,55	5,88	2,34	6,19	6,90	7,96	8,09	9,00	4,64
Цветность, градусы (21)	133	114	114	94	160	177	123	200	—	145	160	133	80
Перманганатная окисляемость, мг O/л (22)	19,5	40,0	49,6	59,3	59,0	62,8	51,2	59,2	51,2	30,0	29,12	16,22	12,6
Бихроматная окисляемость, мг O/л (23)	34,6	114,8	148,5	193,6	242,4	164,2	99,8	144	195,0	—	98,5	106,65	28,8
Фенолы, мг/л (24)	0,012	—	0,016	—	0,130	—	—	0,105	—	следы (30)	0,009	0,008	0,009

[Key on following page]

Key: [to Table 1 on preceding pages]

1. Constituents
2. Background
3. Days
4. third
5. fifth
6. tenth
7. fifteenth
8. twenty-fifth
9. fortieth
10. forty-fifth
11. sixtieth
12. nintieth
13. one hundred-twentieth
14. two hundred-fifth
15. two hundred-seventieth
16. Willow grass
17. $PO_{4\ total}'''$, mg P/liter
18. $PO_{4\ plant}'''$, mg P/liter
19. mg N/liter
20. mg/liter
21. Color index, degrees
22. Permanganate oxidizability mg O/liter
23. Bichromate oxidizability, mg O/liter
24. Phenols, mg/liter
25. Perfoliate pondweed
26. Hornwort
27. Cat-tail
28. Water thyme
29. Common water plaintain
30. Traces

Table 2. Maximum Content of Organic and Biogenic Substances Released per Gram of Air-Dried Matter in Higher Aquatic Plants in 1 Liter Water

(1) Ингредиенты	(2) Горец земноводный		(3) Рдест пронзеннолистный		(4) Роголистник		(5) Рогоз		(6) Элодея		(7) Частуха подорожниковая	
	(8) День экспозиции	(9) мг/л	(8) День экспозиции	(9) мг/л	(8) День экспозиции	(9) мг/л	(8) День экспозиции	(9) мг/л	(8) День экспозиции	(9) мг/л	(8) День экспозиции	(9) мг/л
NH_4', мг N/л (10)	(19) 60-й	16,81	(19) 60-й	1',71	(19) 60-й	15,03	(19) 60-й	9,42	(19) 60-й	11,6	(19) 60-й	20,07
NO_3', мг N/л (10)	(20) 300-й	0,039	(23) 205-й	0,208	(29) 10-й	0,291	(21) 45-й	0,20	(29) 25-й	0,06	(24) 15-й	0,08
$PO_{4\,общ}'''$, мг P/л (11)	(21) 45-й	2,87	(22) 90-й	1,55	(29) 25-й	2,25	(29) 25-й	2,69	(30) 40-й	3,53	(29) 25-й	4,40
$PO_{4\,раств}'''$, мг P/л (12)	(22) 90-й	2,66	(22) 90-й	1,75	(29) 25-й	2,19	(29) 25-й	2,31	(22) 90-й	2,57	(31) 35-й	4,06
Si, мг/л (13)	(23) 205-й	3,42	(22) 90-й	4,46	(23) 205-й	9,73	(23) 205-й	2,97	(23) 205-й	2,29	(29) 10-й	3,92
Органический азот, мг/л (14)	(24) 15-й	5,02	(28) 36-й	5,86	(24) 15-й	6,40	(26) 46-й	5,0	(24) 15-й	5,87	(24) 15-й	11,60
" углерод, мг/л (15)	(25) 3-й	27,6	(24) 15-й	34,1	(29) 10-й	35,9	(19) 60-й	31,9	(24) 15-й	26,9	(24) 15-й	50,0
Фенолы, мг/л (16)	(26) 46-й	0,035	(24) 15-й	0,033	(24) 15-й	0,007	(26) 46-й	0,018	(24) 15-й	0,08	(24) 15-й	0,011
Гуминовые, мг/л (17)	(27) 5-й	19,0	(27) 5-й	22,0	(27) 5-й	10,0	(30) 130-й	14,0	(24) 15-й	8,0	(24) 15-й	27,0
Цветность, градусы (18)	(26) 46-й	25	(28) 26-й	46	(28) 26-й	68	(22) 90-й	40	(28) 26-й	107	(26) 46-й	65

[Key on following page]

Key: [to Table 2 on preceding page]

1. Constituents
2. Willow grass
3. Perfoliate pondweed
4. Hornwort thyme
5. Cat-tail
6. Water thyme
7. Common water plaintain
8. Day of exposure
9. mg/liter
10. mg N/liter
11. $PO_4'''_{total}$, mg P/liter
12. $PO_4'''_{plant}$, mg P/liter
13. mg/liter
14. Organic nitrogen, mg/liter
15. Organic carbon, mg/liter
16. Phenols, mg/liter
17. Humic constituents, mg/liter
18. Color index, degrees
19. 60th
20. 300th
21. 45th
22. 90th
23. 205th
24. 15th
25. 3rd
26. 46th
27. 5th
28. 36th
29. 25th
30. 130th
31. 35th

and are mineralized and allow us--to a certain approximation--to calculate the fraction of organic plant matter in the total amount, determined analytically in studies of inland waters.

By way of example, we cite the calculation for the Kiev Reservoir. From I. L. Korelyakova's data [5], up to 65 percent of higher aquatic plants are formed in the upper shallow part of this body of water; the yield is 44,000 tons/year over the entire shallow part of the reservoir. Dying and mineralizing of this vegetation even in the first few months accumulates significant amounts of organic and biogenic substances in the water (Table 3). Compared with the deep-water zone, their content in the shallow area rises: by 10-25 percent for carbon and nitrogen; to 50 percent, for phenols; by 50-85 percent, for mineral nitrogen; by 100 percent, for phosphorus; and to 6 percent, for silicon. The fraction of vegetative (autochthonic) matter for the entire body of water in the period of the maximum content of these constituents in the water is: 1.5-4 percent, for organic compounds, and 8-17 percent, for biogenic compounds.

Conclusion

Higher aquatic vegetation, after dying and mineralizing, can serve as a prime source of organic and biogenic substances accumulating in water. When this plant life is at a concentration (moist weight) of up to 10 g/liter water, during the first days the oxygen regime substantially deteriorates and the anaerobic conditions of mineralization of plant remains persist from 25 to 120 days. The water accumulates a large amount of biochemically unstable organic compounds and in it saprophytic, proteolytic, ammonifying and denitrifying bacteria develop intensively. As the C:N ratios narrow, ammonia

Table 3. Accumulation of Organic and Biogenic Substances in the Shallow Part of the Kiev Reservoir in Summer

(1) Ингредиенты	(2) Количество (3) т	(4) мг/л	(1) Ингредиенты	(2) Количество т	мг/л
(5) Органический углерод	1217,0	1,83	Аммонийный азот (9)	535,2	0,85
(6) Органический азот	252,1	0,37	Нитратный азот (10)	6,9	0,01
(7) Гуминовые вещества	658,1	1,00	Фосфор общий (11)	104,3	0,16
(8) Фенолы	18,6	0,03	Фосфор растворенный (12)	94,3	0,15
			Кремний (13)	164,9	0,26

Key:

1. Constituents
2. Amount
3. tons
4. mg/liter
5. Organic carbon
6. Organic nitrogen
7. Humic compounds
8. Phenols
9. Ammonia nitrogen
10. Nitrate nitrogen
11. Total phosphorus
12. Solute phosphorus
13. Silicon

nitrogen accumulates; and the content of CO_2 and mineral derivatives of nitrogen and phosphorus increases. The count of saprophytic microorganisms and the rate of accumulation of organic and biogenic substances are the highest in the first two ten-day periods of plant contact with water. By the second month of mineralization the amount of biochemically stable organic substances rises; the C:N ratio becomes larger; and there is a decrease in the content of saprophytic, proteolytic, anaerobic, cellulosic and ammonifying bacteria. During this period nitrification intensifies.

At the maximum release of organic and biogenic substances into the water, the content of organic nitrogen and carbon exceeds the background values by 1.3-10 times; and the content of mineral derivatives of nitrogen and phosphorus--by 11-70 times. At maximum mineralization, 1 g of the air-dry mass of aquatic plants produces in 1 liter of water, on the average, 1.43 times more carbon, 2.23 times more organic nitrogen, 6 times more ammonia nitrogen, 2 times more nitrate nitrogen, 2-3.5 times more phosphate phosphorus and 2.2 times more silicon than 1 g of mixed arboreal vegetation. The accumulation of orgaic and biogenic substances during the mineralization of macrophytes occurs during 1-2 months and that of arboreal plants--during 5 months.

These calculations give us an idea of the order of magnitude of organic and biogenic substances released by vegetation during dying and mineralizing; the calculations help in solving the problem of what role various factors play in forming these substances in inland waters.

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